

## *Appendix: Overviews of Selected Examples*

### ***Native prairie restoration on the northern Great Plains***

Less than 3 percent of the original vast landscape of native prairies survives across the northern Great Plains. Invasive plant species compound the threats to remnant prairies from habitat fragmentation and development. Prairie grasses and wildflowers such as sideoats grama, big bluestem, prairie blazingstar, and ox-eye sunflower are being overgrown by invasions of cool-season exotic grasses like smooth brome and Kentucky bluegrass, mainly because of the elimination of fire. The restoration of native plant composition in tall-grass and mixed-grass prairies helps to reverse environmental damage, improve water quality, preserve animal habitats, and support species diversity. On national wildlife refuges in the northern Great Plains states, fire and other disturbances such as grazing and haying have been suppressed for decades. By reintroducing disturbance, refuge managers hope to control invasive plants and restore a high proportion of native species. Given the current state of a particular refuge, managers face annual decisions about whether to burn, graze, or hay at all – and if so, which option, and in what manner of application. The biology of the system is poorly understood, as are the effects of treatments, particularly over the long time frames relevant to restoration. Therefore, refuge managers use adaptive management to overcome uncertainty about the best treatment to apply at each point in time to reach the long-term objective of high native composition at least cost.

### ***Endangered mussel translocation***

Almost one-third of the world's freshwater mussel species occur in the continental United States, which has the world's most diverse mussel fauna. Yet in the last 100 years, no other wide-ranging group has suffered a greater decline. Mussels are filter feeders that are important conduits of the energy fixed by phytoplankton photosynthesis to other parts of the food web. They filter contaminants, sediments, and nutrients from the water column, and hence are sensitive to siltation, pollution, agricultural runoff, impoundments, and invasive species. Their presence (or absence) is a good indicator of water quality and the integrity of ecological processes in a watershed. Northern riffleshell mussels have disappeared from their former range in the Ohio and Maumee River drainages to such a degree that they are now endangered. When bridge construction on the Allegheny River resulted in a formal Endangered Species Act consultation with the Fish and Wildlife Service, a mussel relocation program was mandated. Almost 1,800 riffleshells from the Allegheny were translocated to eight sites in a 2-mile reach of the Big Darby Creek, Ohio, where a small remnant population still existed within the species' historic range. Translocation will continue to be an important recovery strategy, and adaptive management will be used to apply information about the conditions most conducive to survival and reproductive success of the Big Darby mussels to future mussel restoration efforts.

### ***Wyoming Landscape Conservation Initiative***

Wyoming's Green River basin contains some of the nation's best sagebrush, mountain shrub, aspen, and riverine habitats. These habitats are crucial for deer, elk, bighorn sheep, pronghorn antelope, and threatened sagebrush-dependent species such as the greater sage grouse and pygmy rabbit. Almost three-quarters of the basin's 6 million hectares are public lands; the remaining lands consist of family farms and ranches. Abundant reserves of minerals and natural gas, oil, coal, and wind make the area a hotspot of industrial energy development. The Bureau of Land Management manages federal land and grants leases for energy development. The Wyoming Landscape Conservation Initiative was launched in 2007 to conserve and enhance wildlife habitat as much as possible in areas of oil, gas, and other resource development. It is a consortium of federal, state, and local agencies; environmental and recreation groups; industry; and private landowners. As energy operations continue, adaptive management will be used to share information among stakeholders, prioritize habitat enhancement projects, and advocate best practices in reclamation and mitigation of industrial development.

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## ***New England shrub habitats for rabbits and migratory birds***

Profound alterations in land use have resulted in loss of early successional forest habitats characterized by thickets of native shrubs in the northeastern United States. The introduction of aggressive exotic invasive species such as the multiflora rose, glossy buckthorn, and honeysuckles, which choke native shrubs, has changed the vegetative composition of the thicket habitats available to species that depend on these habitats. The New England cottontail rabbit and Neotropical migrant birds like warblers and vireos have declined along with native shrub communities. The New England cottontail is a candidate for federal listing under the Endangered Species Act and requires shrub habitats with a high stem density. Fall-migrating land birds rest and feed in thicket habitats, gaining energy from fruits of several native shrub species. Managers of National Wildlife Refuges want to restore biological integrity and diversity of shrub habitats sufficient to support migrant land birds and a sustainable population of New England cottontail rabbits. Vegetation treatment options include low- and medium-intensity treatments that incorporate a combination of mechanical and chemical means to control invasive species, and methods to propagate native shrubs. Adaptive management will be used to determine how much effort is needed to restore native shrub communities at the lowest cost.

## ***Etowah River endangered stream fishes***

The southern Appalachian highlands are a global hotspot of fish endemism. The Etowah River in northwestern Georgia supports four endemic fishes, as well as another eight species endemic to the greater Mobile River basin. These and other aquatic species are at risk from urban development and population growth in the Atlanta metropolitan area. The major aquatic stressor is storm-water runoff, in addition to sedimentation, road and utility line crossings, riparian buffer loss, and reservoir impoundments. Three Etowah endemic fishes, darters in the perch family, are already federally listed under the Endangered Species Act. The Act prohibits actions that result in harm to listed species or their habitats, unless explicitly permitted. Adaptive management connects to Endangered Species Act processes by means of the Habitat Conservation Plan (HCP). The Etowah HCP, presented to the Fish and Wildlife Service for approval, incorporates concrete policies (such as runoff limits) for reducing the impacts of urbanization on the endangered darters. It uses models to predict species abundance given HCP implementation, and requires monitoring to provide new information on fishes' responses to development. If actual responses differ from those predicted, the HCP will allow adjustment of urban development policies.

## ***Blanca wetlands***

For thousands of years, the lakes, marshes, and shallow playa basins of the San Luis Valley in southern Colorado filled with snow-melt runoff in late spring and were dry by late summer. By 1950, the basins had dried up entirely due to drainage, wetland loss, and diversion of traditional source waters. In 1965, the Bureau of Land Management began a series of wildlife habitat projects to restore some of the San Luis Valley's dry playa basins to their historic wetland characteristics. Today, the Blanca wetlands site is intensively managed for waterbird, waterfowl, and shorebird habitat. It encompasses over 6,200 hectares of low dunes and depressions that are seasonally flooded by artesian water or canals. As water flows by gravity through the reserve, ponds, marshes, subsaline wetlands, and hypersaline playas are produced sequentially, resulting in a diverse mosaic of wetland habitats. Blanca is one of Colorado's most significant wetland areas, with breeding populations of the white-faced ibis and western snowy plover as well as native amphibians. Adaptive management is used to manage local water flows in order to produce the salinity levels and seasonal vegetation needed by particular species groups.

## ***Cape Cod National Seashore wind turbines***

The seas off Cape Cod, a peninsula that extends nearly 100 kilometers into the Atlantic Ocean off the coast of Massachusetts, have been called an ocean graveyard. Legendary marine storms have resulted in a rich maritime history. Over 3,000 shipwrecks occurred on the Cape over the past 300 years, with an average of 2 wrecks every month during

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the winters of the early 1800s. Lighthouses lit by whale-oil lamps, and an efficient lifesaving service put in place by the national government in 1872, helped to reduce the number of shipwreck casualties. Today, the National Park Service manages many unique historic structures and cultural resources associated with the Cape's maritime past, as well as its marine and terrestrial ecosystems, protected in nearly 18,000 hectares of the Cape Cod National Seashore. The winds that once drove ships into treacherous shoals will be used to run wind turbines at two locations in the park. The National Park Service's Climate Friendly Parks program aims to power park facilities sustainably, with reduced greenhouse gas emissions. Adaptive management will be used to adjust turbine operations daily or seasonally in order to minimize collisions with bats and birds, which themselves are important park resources.

### *Prairie pothole restoration*

When the glaciers of the last ice age receded from the upper Midwest, they left behind millions of shallow depressions – prairie potholes – that fill with snow-melt and rain in the spring. The prairie pothole region is the heart of what was once the world's largest grassland. Millions of ducks and geese pass through this region each spring to nest in the grasslands. It is also important migration habitat for waterfowl breeding in the northern boreal forests and the Arctic. In addition to providing habitat for waterfowl and many other animal species, the pothole wetlands control floods, filter out sediments and contaminants, and recharge groundwater. From the 1950s to the 1980s, thousands of these small wetlands in North and South Dakota and parts of Nebraska, Minnesota, and Iowa were drained, filled, and converted to agriculture. Now, the Minnesota Private Lands Program, part of the National Wildlife Refuge System, the U.S. Department of Agriculture's Natural Resources Conservation Service, and the Minnesota Department of Natural Resources are collaborating with private landowners to restore prairie pothole wetlands in Minnesota. Their objective is to restore healthy, functioning wetlands across the landscape for waterfowl and migratory bird breeding habitat. Removing the extra sediment from the historic basin as part of the restoration process may expose the native seed bank, thus supporting native wetland revegetation. The primary uncertainty is whether or not sediment excavation, in addition to the usual practice of restoring hydrology, will lead to a higher-quality wetland restoration than simply restoring hydrology. Adaptive management is being used to determine if the benefit of sediment removal justifies the additional cost.

### *Las Cienegas*

A small part of the area that was once the 400,000-hectare Empire Ranch in southeast Arizona contains some of the rarest habitat types in the Southwest. The cienegas (marshlands), riparian cottonwood–willow forests, sacaton grasslands, mesquite bosques, and semi-desert grasslands are part of 18,000 hectares of grassland and oak savanna woodland, the Las Cienegas National Conservation Area, watered by the perennial stream of the Cienega Creek. The area, now part of the Bureau of Land Management's National Landscape Conservation System, was acquired by the Bureau in 1988 and was designated a national conservation area in 2000. It supports six endangered species and many other special status species, such as the threatened Chiricahua leopard frog. The historic Empire Ranch house has been preserved; cattle-grazing operations continue under a Bureau of Land Management lease within the conservation area. Because the area is only an hour from Tucson, development threatens these protected lands with overuse of water, introduction of exotic invasive plant and animal species, and other problems. Adaptive management is used to manage vegetation treatments for grassland restoration in upland areas, and to manage aquatic habitats for federally listed species.

### *Columbia River chinook salmon*

For hundreds of miles upstream, the rivers of the Northwest once boiled with millions of chinook and other salmon migrating from the Pacific Ocean to spawn in the streams of their birth. After years at sea, each fish finds its way home to its own natal stream. By the 1890s, dams were affecting salmon runs. Hydroelectric, flood-control, and irrigation projects eventually reduced the area available to salmon by half and led to precipitous declines. Today, out of approximately 1,000 native migratory salmon stocks on the West Coast, 106 are extinct and 314 are at risk of extinction. In the Columbia River, there are three major races of chinook, which enter the river in spring, summer, or fall runs. The races

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also vary in the age and timing of descent to the sea by the finger-sized juveniles. The Columbia's fall chinook stock is one of the more productive naturally reproducing stocks in a river system where many salmonids are declining. River flows modified by upstream hydropower dams have been found to be a major factor affecting fall chinook production. Inadequate water supply and extreme fluctuations in water releases have caused spawning grounds to dry out, thus killing eggs and young fish. In a complex regulatory milieu involving federally and privately owned dams, federal and state agencies, and Indian nations, conditions for dam relicensing by the Federal Energy Regulatory Commission resulted in a program of specific water releases to help limit the risk that fish will spawn in areas that dry out. Within the constraint of maintaining hydropower supply, adaptive management is being used to manipulate flows to protect spawning grounds and thus enhance fall chinook reproduction and recruitment in the Hanford Reach of the Columbia.

### ***Florida scrub-jay habitat***

The endemic Florida scrub-jay is designated as threatened under the Endangered Species Act. Scrub-jays are restricted to Florida scrub, a rare habitat characterized by evergreen, xeromorphic shrubs including oaks, repent palms, and ericaceous shrubs. Scrub is maintained by frequent fires; however, fire suppression and landscape fragmentation over many years have produced scrub communities that no longer can support scrub-jay populations. Scrub-jays at Merritt Island National Wildlife Refuge and adjacent government properties constitute a core population within the species' shrinking range. Though the refuge contains over 8,500 hectares of oak scrub, in 2005 only 23 percent was considered to be in optimal condition for scrub-jays. Since 1993 more emphasis has been placed on restoration and maintenance of wildlife habitat, but refuge managers face constraints on the timing and location of burns because of fire and smoke hazards to the nearby Kennedy Space Center and neighboring cities, suburbs, and the Cape Canaveral Air Force Station. Given these constraints, managers must decide what frequency of fire in a collection of management units will best ensure the long-term persistence of the refuge's scrub-jay population. Scrub sites with a long history of fire suppression also require cutting of the scrub to ensure an effective burn. Decisions concerning cutting and prescribed burning are difficult because of incomplete understanding of fire dynamics, plant community succession, and the demographic responses of scrub-jays to environmental factors. Adaptive management identifies management strategies that account for these uncertainties, while using what is learned to adjust and improve scrub management over time.

### ***Tallapoosa River – R.L. Harris Dam***

Extensive hydropower development has altered riverine habitats in the southeastern United States, which is a global center of freshwater fish and invertebrate diversity. The Tallapoosa River in east central Alabama is a priority area for aquatic conservation, with a native fish assemblage of 57 species, including 5 species endemic to the Tallapoosa River system. Of these, four fishes and one mussel are considered to be "at risk" by the Fish and Wildlife Service. Fish and invertebrate populations in one of the highest-quality segments of Tallapoosa habitat were threatened with extirpation by extreme low flows, flow instability, and altered temperatures resulting from daily pulsed flow releases for hydropower at the utility-owned R.L. Harris Dam. The Fish and Wildlife Service has been evaluating relicensing of more than 200 dams in the southeastern United States – including the Harris dam – that are licensed by the Federal Energy Regulatory Commission (FERC). Through the Southern Rivers Integrated Science Initiative, the Service has recognized the great need for new approaches to evaluate dam relicensing, and new strategies to mitigate the impacts of dam operations on aquatic communities. Rather than the one-time fixed flow regime typical of FERC relicensing prescriptions, adaptive management has been used on the Tallapoosa since 2005 to allow for the adjustment of flow management based on what is learned from system responses. This project is intended to provide a template for incorporating adaptive management and decision support into the FERC relicensing process.

### ***Red knots and horseshoe crabs***

The sandy beaches of Delaware Bay in Delaware and New Jersey are globally important spawning grounds for Atlantic horseshoe crabs and stopover habitat for long-distance migratory shorebirds such as the red knot. Annually, the birds stop in Delaware Bay during May to rest and replenish their energy reserves while migrating from wintering grounds

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in temperate and tropical regions to breeding grounds in Arctic regions. They stop in the bay to exploit the seasonally superabundant horseshoe crab eggs deposited on the beaches by millions of crabs that spawn during the lunar tides each spring. Throughout the 1990s a growing and unregulated harvest of horseshoe crabs for use as bait in eel and whelk fisheries led to a decline in numbers of spawning crabs. In the late 1990s, monitoring data began to show major declines in red knot abundance. Shorebird scientists and advocacy groups blamed horseshoe crab fishing as the root cause of the red knot decline, while other scientists and horseshoe crab fishermen's groups argued that red knots are not solely reliant on horseshoe crab eggs for food, and that some other environmental factor must be responsible for the decline in red knot numbers. Conservationists called for a complete cessation of horseshoe crab fishing in the Delaware Bay, while others called for moderate regulations to protect the horseshoe crab fishery. Adaptive management was initiated on this contentious issue, with a goal of identifying a sustainable horseshoe crab harvest strategy that protects red knots and enables learning about how the system functions.

### *Red-cockaded woodpeckers in southeastern pine forests*

The endangered red-cockaded woodpecker is a cooperatively breeding bird whose social system depends on mature old-growth pine forests of the southeastern United States. Family groups, including helpers at the nest, may be as large as nine birds. A woodpecker group roosts and nests in a cluster of living pines in which cavities have been excavated; each bird has its own cavity for roosting. The cluster may include 1 to 30 cavity trees. Preferred cluster sites are mature, park-like pine stands about 4 hectares in area; the group defends a territory of perhaps 80 hectares around the cluster. Birds select very old trees for the excavation of nesting cavities; other habitat requirements include few or no midstory trees and the presence of an adequate understory, but the old-growth condition is the underlying requirement. These habitat conditions were routinely met by the historic disturbances that shaped the pine forests. Red-cockaded woodpeckers once occurred in other forest types from New Jersey to Florida and west to Oklahoma and Missouri, including loblolly pine forests of the Piedmont. The Recovery Plan for the species calls for establishment of primary and secondary populations across different forest types and provinces. One recovery target is the Fish and Wildlife Service's Piedmont National Wildlife Refuge and Chattahoochee-Oconee National Forest complex in central Georgia. These lands came into federal ownership in the 1930s after the collapse of cotton farming in the region, after which forests of mixed loblolly pine and hardwoods have become established. The red-cockaded woodpecker population in this forest complex is the largest in the Piedmont physiographic province. Creation and long-term maintenance of old-growth forest is critical for sustaining this population. Adaptive management is used to account for uncertainty about the maximum attainable amount of old-growth loblolly pine forest, and to make decisions about the harvest strategy to obtain the most old-growth habitat over the long term.

### *Golden eagles in Denali*

Throughout the Northern Hemisphere, the golden eagle is the pre-eminent diurnal predator of medium-sized birds and mammals in open country. The mountainous regions of Alaska's Denali National Park support the highest nesting density of golden eagles in North America, with undisturbed cliffs for nests that are used over decades or even centuries, and abundant snowshoe hares, ptarmigan, and other prey. Nesting eagles are sensitive to human disturbance, and the National Park Service must limit human presence near nest sites in order to maintain Denali's eagle population. Eagles may occupy any of nearly 100 potential nesting sites across the northeastern part of the park between March and September during the course of their reproductive cycle of nest repair, egg-laying, and rearing eaglets to independence. This means that a large portion of Denali, a premier national wilderness recreation destination during the summer months, could potentially be off limits to hiking and other enjoyment of the park. To reconcile the conflicting demands of maximizing recreational access to as much of the park as possible, and minimizing disturbance of nesting eagles, the national park uses adaptive management to make annual decisions about whether and how much to limit recreational hiking near nesting areas.



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## *Five Rivers forest landscape management study*

The towering forests of the Pacific Northwest, growing over the course of millennia, have shaped the evolution of many species dependent on late-succession and riparian habitat. For example, the marbled murrelet, a coastal seabird, requires mature old-growth forest for nesting; the northern spotted owl, a predatory nocturnal bird, hunts and breeds in old-growth stands; and the Siskiyou Mountains salamander, an endemic amphibian, is found only in deep forests along the Oregon–Washington border. The Northwest Forest Plan revolutionized management of federal lands in the Pacific Northwest to accommodate these and other species, which were thought to be declining as a result of extensive timber production that eliminated old-growth habitats. Management of many forest plantations, which make up about 50 percent of the land area in the central Oregon Coast Range, was redirected from producing timber to growing late-successional stands. Uncertainty was clearly acknowledged by managers, who recognized that no one had ever grown late-successional stands from plantations before. The Forest Service designed a landscape-scale project on 4,800 hectares of the Siuslaw National Forest to address the controversy about whether plantations should be thinned, and to what degree, or whether they should be left to develop on their own. The project implemented adaptive management in comparing three strategies with a standard random-block design. By developing the rationale for all strategies and demonstrating their implementation, this study has already helped change forest management in coastal national forest lands. One of the three strategies, involving wide commercial thinning of existing plantations to speed development of late-successional vegetation structure, was previously controversial and has now become widely accepted.

## *Adaptive management of waterfowl hunting*

Adaptive harvest management was developed to deal explicitly with multiple sources of uncertainty in the regulation of sport waterfowl hunting in North America. Early each year, the Fish and Wildlife Service announces its intent to establish waterfowl hunting regulations and provides the schedule of public rule-making under authority of the Migratory Bird Treaty Act of 1918 (as amended) and other relevant laws. The agency director appoints a Migratory Bird Regulations Committee with representatives of the Waterfowl Flyway Councils, which presides over the process and is responsible for regulatory recommendations. Adaptive harvest management is the framework adopted by the Committee to deal with uncertainty in the regulation of sport waterfowl hunting in North America, including uncontrolled environmental variation, partial control of harvests, and uncertainty concerning waterfowl population dynamics and the impact of harvest. The approach produces optimal regulatory policies that account for each possible combination of breeding population size, environmental conditions, and the current level of understanding. A regulatory choice is identified each year, and post-decision monitoring data are used to update biological understanding for the next year. In this way harvest policy evolves adaptively over time as new knowledge is incorporated.

## *Biscuit Fire landscape management after the wildfire*

Fire-adapted ecosystems were historically maintained in the Pacific Northwest by relatively frequent wildfires of low to moderate intensity. In Oregon's Siskiyou National Forest, an average of 8,000 hectares burned annually until the 1940s, but over the next 50 years that figure fell by almost 90 percent. Between 1940 and 1990, large, plume-driven forest wildfires became uncommon in Oregon and Washington as a result of systematic and effective fire suppression. However, an unintended consequence, the decades-long buildup of dead fuels, probably contributed to recently increasing numbers of very large fires. In 2002, drought, heat, and other climate factors led to a series of Pacific Northwest wildfires culminating in the nation's biggest fire, the Biscuit Complex fire, which consumed about 200,000 hectares of forest. The magnitude of the Biscuit fire and new mandates from the Northwest Forest Plan regarding late-succession and riparian habitats created much uncertainty about the most appropriate forest management after a wildfire. Rather than choosing the typical method of "salvage" logging and replanting, Forest Service researchers helped develop a peer-reviewed study plan that was adopted in the final Record of Decision for the Biscuit Fire Recovery Project. Adaptive management is being used to compare three competent management strategies on 14,500 hectares of land in the Rogue River–Siskiyou National Forest and Medford District of the Bureau of Land Management, in order to understand better how to manage forests after large wildfires.

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### ***Laysan duck translocation***

The Laysan duck represents a great success in endangered species recovery. It is a critically endangered dabbling duck endemic to the Hawaiian islands; it became confined to Laysan Island after humans introduced rats to the Hawaiian islands. The ducks do not disperse from Laysan today, but sub-fossil remains show that the species was once widespread in the Hawaiian islands. Low abundance, random disasters, and the limited carrying capacity of the fragile ecosystems on tiny islands are the main threats to its persistence. Since the severe contraction of the range from the main Hawaiian islands, random events that have already occurred include the accidental introduction of noxious competitors (rabbits), extreme weather (droughts, hurricanes), and disease epizootics (parasitic nematode, avian botulism). Twice during the last century, the single population was pushed to the brink of extinction (in 1911, only 11 individuals remained). Living on relatively low-lying islands, this species is now susceptible to climate change through sea-level rise and shifts in suitable climatic conditions. Creation of other wild populations within the duck's former range became a high priority in the Fish and Wildlife Service's Laysan Duck Recovery Plan. During 2004–2005, an initial translocation to Midway Atoll, part of the National Wildlife Refuge System, established another breeding population. Additional populations on different islands are planned in the northwestern Hawaiian islands, part of the Papahānaumokuākea Marine National Monument, which is jointly managed by the Service and the National Oceanic and Atmospheric Administration, in close coordination with the state of Hawaii. Adaptive management will guide the selection of the best islands for further translocations.

### ***Northwest Forest Plan***

The northern spotted owl is a nocturnal hunter of flying squirrels, birds, and other prey deep in ancient stands of conifers in the Pacific Northwest. It requires old-growth forest habitat for breeding and foraging. As a federally listed threatened species, it became the focal point of a national debate over the cumulative effects of timber harvesting and losses of late-successional stands on federal lands in the Pacific Northwest. A 1991 injunction halted timber harvest on 9.7 million hectares of federal lands in the owl's range. President Clinton intervened in 1993 to set up a science-based forest ecosystem management assessment team that helped frame a Record of Decision, creating the Northwest Forest Plan to revamp management of these lands. Court and planning documents acknowledged high levels of uncertainty and established adaptive management as the cornerstone of this plan. Following a 10-year period of monitoring forests in 10 adaptive management areas delineated in the plan, evaluation of evidence in a broad and integrative context helped federal agency regional executives to improve the Northwest's regional adaptive management framework and to assess priority questions by means of adaptive management concepts. The regional framework helps to pull together individual adaptive management efforts of the Northwest Forest Plan, such as the Five Rivers and Biscuit landscape projects as well as other research activities, and to interpret them together in a formal process aimed at improving land-management decision making at the regional level.

# Glossary

## ***Adaptive decision making***

Decision making that accounts for what is uncertain as well as what is known about the processes that influence natural resource behavior through time and the influence of management on resource changes. Adaptive decision making seeks to reduce this uncertainty and thereby improve management through enhanced understanding of management effects.

## ***Adaptive management***

This term is used interchangeably with adaptive decision making.

## ***Bayes' rule***

A technique used to propagate structural uncertainty through time; the technique combines measures of uncertainty at each point in time with data from post-decision monitoring to produce new measures for the next time.

## ***Climate change adaptation***

Adaptation in natural or human systems to a new or changing environment. Adaptation refers to adjustments in natural or human systems that are intended to reduce vulnerability to actual or anticipated climate change, or to exploit opportunities arising from that change.

## ***Climate change mitigation***

Actions resulting in reductions in the degree or intensity of greenhouse gas emissions. Sometimes referred to as abatement.

## ***Decision problem***

In natural resources, a problem that requires managers to make a decision, once or repeatedly, that will influence resource conditions or processes. In adaptive management, the decision problem involves iterative decision making, with the opportunity to learn through time and adjust management strategies on the basis of what is learned.

## ***Ecosystem services***

Goods and services that create value for human users and are derived from ecosystem processes such as nutrient recycling, climate regulation, and maintenance of biodiversity. Examples of ecosystem services include clean drinking water, flood risk reduction, pollination of crops, and decomposition of wastes. Examples of marketable goods provided by ecosystems include lumber and seafood.

## ***Estimation***

The aggregation of field data into measures of resource attributes. Examples include means, variances, and correlation coefficients computed with sample data. Multiple estimators are always available for any resource attribute, and the choice of which particular estimator to use is based on features such as statistical bias and precision.

## ***Experimentation***

The imposition of treatments on subjects or experimental units for the explicit purpose of learning about treatment effects by observing outcomes. Ideally, experimentation involves random allocation of treatments to experimental units, replication of treatments, and the use of controls for comparative purposes.



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## ***Experimental management***

The use of management interventions for the purpose of understanding the effects of management. Interventions are used as experimental treatments, ideally (but infrequently) involving randomization, replication, and experimental control.

## ***Hypothesis***

A suggested but unconfirmed explanation of observed patterns. Hypotheses can take many forms, such as a hypothesized magnitude of a resource attribute or a hypothesized mathematical relationship between attributes. Hypotheses are tested by comparison with field data.

## ***Management by experiment***

An approach to management that recognizes management interventions as experiments, by means of which understanding can be enhanced as management proceeds over time.

## ***Management action***

An action that affects a managed system, and is taken as a result of a management decision. In the context of natural resources, management actions typically influence the status of resources or the processes that control resource dynamics.

## ***Management alternative***

A potential management action. In sequential management, a management action is selected at each point in time from an identified set of management alternatives. The set of management alternatives constrains and influences the choice of a management strategy.

## ***Management decision***

A decision to take a management action. In adaptive management, decision making usually is driven by management objectives, with active stakeholder involvement. Adaptive decision making takes into account both the current status of resources and the level of understanding about them.

## ***Management option***

This term is used interchangeably with management alternative.

## ***Management strategy***

A prescription of management actions designed to meet management objectives. In the context of adaptive management, a management strategy describes management actions to be taken at specific times. At a particular point in time, the action that is prescribed depends on the current resource status and the level of understanding about resource dynamics. Management strategies are often expressed in terms of resource thresholds, on either side of which a different action is to be taken.

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## ***Model***

Any representation, whether verbal, diagrammatic, or mathematical, of an object or phenomenon. Natural resource models usually characterize resource systems in terms of their status and change over time. Models incorporate hypotheses about resource structure and function, and they generate predictions about the effects of management actions.

## ***Non-stationarity***

Directional change in resource structure and function over time. Natural resource systems with ecological processes and parameters that vary directionally over time are non-stationary. Similarly, management strategies that vary through time are non-stationary. Natural resources subject to long-term, directional environmental change are likely to exhibit non-stationary behaviors. As an example of directional (non-stationary) environmental change, a stable (stationary) pattern of fluctuation in annual rainfall may become non-stationary because a warming climate induces fluctuations with increasing extremes. In such a case, both minimum rainfall and maximum rainfall would trend directionally upward (or downward) year by year.

## ***Objective***

A desired outcome or performance measure that expresses stakeholder values and serves to guide natural resource decision making and the evaluation of success.

## ***Resilience***

The ability of a system to absorb disturbances and still retain the same basic structure and functions. A resilient system is flexible and forgiving of external shocks. As resilience declines, the magnitude of shocks from which the system cannot recover becomes smaller and smaller. Management for resilience seeks flexible system behaviors that can deliver desired ecosystem goods and services on a sustained basis.

## ***Stakeholders***

Individuals and organizations (e.g., managers, scientists, private citizens, non-governmental organizations) with a vested interest in a shared enterprise. Interests can include an expectation of received benefit, a perceived threat, a prior investment of time or resources, or values shared with others associated with the enterprise. Active engagement of stakeholders promotes the successful implementation of adaptive management.

## ***Sustainability***

The capacity to endure over an extended time. Sustainable resource systems retain their structure, functions, and ability to provide ecological services. Resource management that maintains long-term resource productivity constitutes sustainable management. Sustainability is closely tied to the concept of system resilience.

## ***Threshold***

The limiting value of a resource attribute that triggers a change in management actions. Management strategies often include thresholds, such that one action is specified for resource values less than the threshold and a different action is specified for resource values greater than the threshold.